

EXHAUST GAS TREATMENT APPARATUS AND METHOD

Technical field

The present disclosure relates to an exhaust gas treatment apparatus and an exhaust gas treatment method generally for the treatment of a plurality of pollutant types in exhaust gas.

Background

The International Maritime Organization (IMO) states that, by the year of 2020, the allowed rate of emission of sulphur oxide (SO_x) will be globally reduced to 0.5% except in emission controlled areas (ECAs), where the rate of 0.1% still applies. Nitrogen oxide (NO_x) emission is also aimed to be reduced in the near future, requiring Tier-2 globally and Tier-3 in ECAs and with the possibility of new areas being added.

SO_x is a byproduct of fuel oil combustion, formed when sulphur in the fuel reacts with oxygen. The prime constituent of SO_x is sulphur dioxide (SO₂) and the amount of SO_x formed depends primarily on the concentration of sulphur in the fuel. The formation of NO_x occurs during the diesel engine combustion process where nitrogen reacts with oxygen to form predominantly nitric oxide (NO) and a small amount of nitrogen dioxide (NO₂). The temperature of reaction and the concentration of available oxygen are the main influencing factors of the formation of NO_x.

Internal combustion units, such as diesel engines employed on marine vessels and running on fuel with a sulphur content exceeding 0.5%, conventionally require a scrubber for SO_x treatment in conjunction with another device implementing an Exhaust Gas Recirculation (EGR) process, a water emulsion
5 process or a Selective Catalytic Reduction (SCR) process for reduction of NO_x emission. Existing technologies, however, result in higher footprint, weight and power consumption.

It is desirable to provide an exhaust gas treatment apparatus and an exhaust
10 gas treatment method, which address at least one of the drawbacks of the prior art and/or to provide the public with a useful choice.

Summary

According to one aspect, there is provided an exhaust gas treatment apparatus,
15 comprising: a treatment chamber; a gas inlet adapted to introduce exhaust gas into the treatment chamber, the introduced exhaust gas having a plurality of pollutant types; a cooling device configured to introduce a cooling medium into the treatment chamber to cool the introduced exhaust gas; a reagent delivery device configured to introduce a reagent into the treatment chamber to react
20 with the plurality of pollutant types of the cooled exhaust gas to produce an oxidised byproduct; and a gas outlet adapted to discharge the oxidised byproduct from the treatment chamber.

The described embodiment is particularly advantageous. By introducing the
25 cooling medium to cool the introduced exhaust gas and then introducing the

reagent to react with the plurality of pollutant types of the cooled exhaust gas, this is effective in treating two or more pollutant types in the same treatment chamber. The harmful/toxic pollutant types are thus converted into an oxidised byproduct which is environmentally friendly. In this way, the undesirable pollutant types in the exhaust gas may be prevented from being discharged into the environment. The apparatus of the present disclosure thus achieves reduced footprint, weight and power consumption.

Preferably, the pollutant types may include sulphur oxide (SO_x) and nitrogen oxide (NO_x). The reagent may include Carbamide. The cooled exhaust gas may have a temperature falling within the range from 70°C to 100°C. It is preferred that the reagent may have a concentration not smaller than 40 g/l. With such an arrangement, SO_x and NO_x in the exhaust gas may be effectively treated prior to being discharged.

15

Preferably, the reagent delivery device may comprise: a plurality of nozzles configured to spray the reagent at the cooled exhaust gas. The reagent may be sprayed inwardly at an angle ranging from 0° to 40°. The reagent may be sprayed outwardly at an angle ranging from 0° to 30°. The reagent may be sprayed to form a plurality of droplets with sizes falling within the range from 0.5 mm to 1.5 mm. The reagent may be sprayed in a full cone spray pattern. Such a nozzle arrangement may ensure that the reagent is sprayed to provide a full coverage for a cross sectional area of a hollow cylindrical body defining the treatment chamber.

20

Preferably, the cooling device may comprise: a plurality of nozzles configured to spray the cooling medium at the introduced exhaust gas. The cooling medium may include at least one of seawater and freshwater, and may be sprayed in a full cone spray pattern.

Preferably, the apparatus may further comprise at least one of: a first deflector configured to block entry of liquid from the cooling device into the gas inlet; and a second deflector configured to block entry of liquid from the reagent delivery device into the cooling device. The at least one of the first deflector and the second deflector may be cone shaped. The at least one of the first deflector and the second deflector may be further configured to reduce a drop in pressure of the exhaust gas across the at least one of the first deflector and the second deflector. The at least one of the first deflector and the second deflector may have a serrated edge. The first deflector in such an arrangement may prevent or reduce water damage of the engine due to entry of liquid from the cooling device into and through the gas inlet. The second deflector in such an arrangement may prevent the reagent from coming into contact and reacting with the exhaust gas prior cooling by the cooling device.

20

Preferably, the apparatus may further comprise a grating configured to cause the cooled exhaust gas passing through the grating to form a plurality of turbulent vortices. By causing the cooled exhaust gas to form turbulent vortices, a time of residence of the cooled exhaust gas at the reagent delivery device and

hence a time of reaction of the cool exhaust gas with the reagent may be extended, allowing a more thorough reaction process to take place and a better treatment result to be achieved.

- 5 Preferably, the apparatus may further comprise a demister configured to demist the oxidised byproduct.

Preferably, at least one of the cooling medium and the reagent is introduced based on a flow rate of the exhaust gas. This arrangement may reduce the
10 overall power consumption.

In a second aspect, there is provided an exhaust gas treatment method, comprising: introducing exhaust gas into a treatment chamber, the introduced exhaust gas having a plurality of pollutant types; introducing a cooling medium
15 into the treatment chamber to cool the introduced exhaust gas; introducing a reagent into the treatment chamber to react with the plurality of pollutant types of the cooled exhaust gas to produce an oxidised byproduct; and discharging the oxidised byproduct from the treatment chamber.

- 20 It is envisaged that features relating to one aspect may be applicable to the other aspects.

Brief Description of the drawings

Example embodiments will now be described hereinafter with reference to the accompanying drawings, wherein like parts are denoted by like reference numerals. Among the drawings:

5 Figure 1 is a schematic cross sectional diagram of an exhaust gas treatment apparatus according to one embodiment of the present disclosure;

 Figure 2 is a flowchart of an exhaust gas treatment method performed by the apparatus of Figure 1, according to one embodiment of the present disclosure;

10 Figure 3 shows two partially enlarged perspective views of a gas inlet and a deflector of the apparatus of Figure 1, arranged side by side to show respective effective areas;

 Figure 4 is a schematic top view of a cylindrical body and the deflector of the apparatus of Figure 1;

15 Figure 5 is a schematic diagram showing nozzles of a reagent delivery device of the apparatus of Figure 1;

 Figure 6 shows a line chart of reaction temperature, pH and concentration of Carbamide as a reagent used by the apparatus of Figure 1;

 Figure 7 is another schematic diagram of the apparatus of Figure 1, in
20 association with a water cooling pump and a control and monitoring system;
and

 Figure 8 is a flowchart of operation of the control and monitoring system of Figure 7.

Detailed Description

Figure 1 shows a cross sectional view of an example embodiment of an exhaust gas treatment apparatus 100, configured to perform an example embodiment of an exhaust gas treatment method 400 (see Figure 2), according to the present disclosure. The apparatus 100 includes a gas inlet 110, a first deflector 120, a cooling device 130, a guide wall 140, a second deflector 150, a grating 160, a reagent delivery device 170, a demister 180 and a gas outlet 190. The apparatus 100 is, in this example, associated with an internal combustion engine (e.g., a diesel engine, not shown) for treatment of exhaust gas and is, in this embodiment, deployed on a marine vessel (not shown). In this particular embodiment, the apparatus 100 is shown to include a hollow cylindrical body 500 defining a treatment chamber 501. The exhaust gas has a plurality of pollutant types.

The gas inlet 110 is adapted to introduce exhaust gas into the treatment chamber 501 (Step 401). Specifically, the gas inlet 110 is arranged at a bottom portion of the cylindrical body 500 and fluidly communicates the treatment chamber 501 with an exhaust pipe (not shown) of the engine. With such an arrangement, exhaust gas from the engine is guided by the exhaust pipe and the gas inlet 110 into the treatment chamber 501. The exhaust gas to be treated has a direction of flow marked by an up-arrow next to the gas inlet 110.

The first deflector 120 is configured to block or reduce entry of liquid from, for example, the cooling device 130 into the gas inlet 110. It should be noted that

such liquid may be any liquid in the treatment chamber 501, and not necessarily be that originating from the cooling device 130. The first deflector 120 is cone shaped and is further configured to direct or guide such deflected liquid to an associated drain (not shown).

5

In this embodiment, the first deflector 120 is further configured to reduce a drop in pressure of the introduced gas across the first deflector 120. Specifically, the first deflector 120 has a size and a location of installation which facilitate the reduction or blockage of entry of liquid from the cooling device 130 or the
10 treatment chamber 501 into the gas inlet 110. Two factors are taken into considerations. One factor is the static and dynamic conditions of the vessel of the engine based on the requirements of the International Convention for the Safety of Life at Sea (SOLAS). The other factor is the back pressure due to the velocity of the exhaust gas traversing the gas inlet 110.

15

The introduced gas experiences an amount of pressure drop that is in a positive relation (or proportional) to a difference between a velocity of the introduced gas below the first deflector 120 and a velocity of the introduced gas peripherally around the first deflector 120 (more particularly, around a peripheral edge of the
20 first deflector 120). In other words, to reduce the pressure drop of the introduced gas across the first deflector 120, the difference between the velocities of the introduced gas at the two locations needs to be reduced. To this end, with reference to Figure 3, by equating an effective cross sectional gas-passage area peripherally around the first deflector 120 (i.e., the disc-

shaped shaded area on the right-hand side) to an effective gas-passage area between the first deflector 120 and the gas inlet 110 (i.e., the cylindrical shaded area on the left-hand side), it is possible to determine a size and a location for the first deflector 120 with respect to the gas inlet 110 for achieving a reduced
 5 pressure drop.

Reference numeral 'H' in Figure 3 marks a vertical distance between the gas inlet 110 and a lowest point of the first deflector 120, more particularly a clearance distance between an opening of the gas inlet 110 and a projection of
 10 said opening on an imaginary plane coinciding with the peripheral edge of the first deflector 120. This consideration is further applicable to an alternative configuration where the first deflector is configured to be flat in shape rather than having a cone shape.

15 In the example embodiment, the first deflector 120 is configured to satisfy the relationships:

$$A_{eff_deflector} = A_{eff_deflector_inlet}$$

$$\pi \left(\frac{ID_{scrubber}}{2} \right)^2 - \pi \left(\frac{ID_{deflector}}{2} \right)^2 = Gas\ Inlet\ Circumference \times H$$

$$\pi \left(\frac{ID_{scrubber}}{2} \right)^2 - \pi (R_{deflector})^2 = \pi (ID_{gas_inlet}) \times H$$

20
$$H = \frac{(R_{deflector} - R_{gas_inlet})}{\tan 22.5^\circ}$$

$$R_{deflector}^2 = \left(\frac{ID_{scrubber}}{2} \right)^2 - (ID_{gas_inlet}) \left[\frac{(R_{deflector} - R_{gas_inlet})}{\tan 22.5^\circ} \right]$$

$$R_{deflector}^2 + \left(\frac{ID_{gas_inlet}}{\tan 22.5^\circ} \right) R_{deflector} - \left[\left(\frac{ID_{gas_inlet}}{\tan 22.5^\circ} \right) R_{gas_inlet} + \left(\frac{ID_{scrubber}}{2} \right)^2 \right] = 0$$

where 'A_{eff_deflector}' represents the disc-shaped effective cross sectional gas-passage area peripherally around the first deflector 120; 'A_{eff_deflector_inlet}' represents the cylindrical effective gas-passage area between the first deflector 120 and the gas inlet 110; 'ID_{scrubber}' represents an internal diameter of the hollow cylindrical body 500 of the apparatus 100; 'ID_{gas_inlet}' represents an internal diameter of the gas inlet 110; 'H' marks the vertical distance between the gas inlet 110 and the lowest point of the first deflector 120; 'R_{deflector}' represents a radius of the first deflector 120 at the lowest point (or the imaginary plane) of the first deflector 120; and 'R_{gas_inlet}' represents a radius of the gas inlet 110 at the highest point (i.e., said opening) of the gas inlet 110.

Using the mathematical equation of $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ where $x = R_{deflector}$, the value of x can be calculated. The value thus obtained is the required radius at the lowest point of the first deflector 120, and is also used to determine the height or the vertical distance 'H' for installation of the first deflector 120 with respect to the gas inlet 110.

Figure 4 shows a top view of the gas inlet 110 (marked by a dashed line) and the first deflector 120 according to an alternative embodiment. The first deflector 120 of the alternative embodiment is further configured to have a serrated edge defining a plurality of sharp protrusions 121 to facilitate the reduction of pressure drop. The number of the protrusions 121 is dependent on the size of

the first deflector 120. Further, these protrusions 121 have a radial length dependent on an amount of space available between the cylindrical body 500 and the first deflector 120. In this alternative embodiment, the protrusions 121 are identical in shape, forming isosceles triangles with an isosceles angle of 45°, which achieves an improved result of pressure drop reduction. After flowing around and past the first deflector 120, the introduced exhaust gas rises towards the cooling device 130.

Referring again to Figure 1, the cooling device 130 is configured to cool the introduced exhaust gas with a cooling medium (Step 402). More specifically, the cooling device 130 is configured to introduce the cooling medium into the treatment chamber 501 to cool the introduced exhaust gas. In this example embodiment, the cooling device 130 includes a plurality of nozzles 131 (referred to below as “the cooling nozzles”) configured to spray the cooling medium at the introduced exhaust gas. The cooling medium may include at least one of seawater and freshwater, and is seawater in this embodiment since the apparatus 100 is deployed on the marine vessel. In this embodiment, the cooled gas has a temperature falling within the range from 70°C to 100°C. However, in other embodiments, the temperature range of the cooled gas may be otherwise and dependent on the reagent used, although it is preferred for the temperature to fall within the range from 90°C to 100°C and to not exceed 100°C for the treatment to be relatively effective. The cooling nozzles 131 may have any suitable configuration. For example, the cooling nozzles 131 may be configured with a spiral full cone spray pattern, which ensures a full coverage of a cross

sectional area of the hollow cylindrical body 500 of the apparatus 100 (by virtue of its full cone spray pattern), and which is resistant to problems such as clogging (by virtue of its spiral design). Maintenance efforts required can thus be reduced. Other nozzle configurations include, for example, full cone, flat spray and hollow cone. After the exhaust gas is cooled by the cooling device 130, the cooled exhaust gas rises towards the second deflector 150 via a passage port 141 defined by the surrounding guide wall 140.

The guide wall 140 includes a first section 142 extending radially and inwardly from the cylindrical body 500, and a second section 143 extending perpendicularly from an innermost end of the first section 142 towards the second deflector 150 to define the passage port 141. In such a configuration, the first section 142 serves to guide the cooled exhaust gas inwardly towards the passage port 141, and the second section 143 serves to guide the cooled exhaust gas through the passage port 141 towards the second deflector 150.

The second deflector 150 is configured to reduce or block entry of liquid from the reagent delivery device 170 into the cooling device 130. The second deflector 150 is similar to the first deflector 120 in shape (cone shaped) and may have a serrated edge. The second deflector 150 may also be fluidly associated with a respective drain (not shown) for discharging liquid deflected by the second deflector 150. The first and second deflectors 120, 150 may be considered to cooperate with each other to reduce or block entry of liquid from the treatment chamber 501 into the gas inlet 110. This arrangement is useful in

preventing engine damage due to liquid infiltration. Furthermore, the relationship between the first deflector 120 and the gas inlet 110 in relation to pressure drop reduction may be applicable to the second deflector 150 and the second section 143 of the guide wall 140. In one arrangement, the second
5 deflector 150 may adopt a configuration similar to that of the first deflector 120 shown in Figure 4. After flowing around and past the second deflector 150, the cooled exhaust gas rises towards the grating 160.

The grating 160 is configured to cause the cooled exhaust gas passing through
10 the grating 160 to form a plurality of turbulent vortices. This arrangement allows the cooled exhaust gas to be more thoroughly treated by extending the residence time of the cooled exhaust gas at the reagent delivery device 170. That is, by extending the time required for the cooled exhaust gas to pass through the reagent delivery device 170, the cooled exhaust gas can be more
15 thoroughly and effectively treated by the reagent. The grating 160 can be a standalone grating or one integrated with the second deflector 150. After flowing through the grating 160 to form the turbulent vortices, the cooled exhaust gas rises towards the reagent delivery device 170.

20 The reagent delivery device 170 is configured to treat the cooled exhaust gas with a reagent corresponding to the plurality of pollutant types of the exhaust gas (Step 403). In particular, the reagent delivery device 170 is configured to introduce the reagent into the treatment chamber 501 to react with the plurality of pollutant types of the cooled exhaust gas to produce an oxidised byproduct.

The reagent delivery device 170 of this embodiment includes a plurality of nozzles 171 (referred to below as “the reagent nozzles”) configured to spray the reagent at the cooled exhaust gas. In this embodiment, the apparatus 100 includes a riser 502 that is disposed at a central axis of the cylindrical body 500 of the apparatus 100. The riser 502 can either be standalone or be connected to any suitable number (e.g., one, two or three) of branches 504 (only one shown in Figure 5) at each annular pipe 503. The annular pipes 503, the riser 502 and the branches 504 are configured for mounting of the reagent nozzles 171 and for fluid communication of the mounted reagent nozzles 171 with a source of the reagent (not shown). The source may include a pump for supplying the reagent to the reagent nozzles 171 via any suitable conduit means, such as pipes. The reagent nozzles 171, similar to the cooling nozzles 131, may for example be full cone nozzles, spiral full cone nozzles, any other variant nozzles, or a combination of these different nozzles. In this example, the reagent nozzles 171 are arranged to spray the reagent uniformly in a full cone spray pattern.

Shown in Figure 5 is an enlarged partial cross sectional view of the reagent delivery device 170. The reagent nozzles 171 mounted on the annular pipes 503 are arranged to spray the reagent inwardly (i.e., towards the riser 502) and downwardly (i.e., towards the second deflector 150) at angles falling within the range from 0° to 40°. On the other hand, the reagent nozzles 171 mounted on the riser 502 and the branches 504 extending from the riser 502 (only one shown in Figure 5) are arranged to spray the reagent outwardly (i.e., towards

the annular pipes 503) and downwardly (i.e., towards the second deflector 150) at angles falling within the range from 0° to 30°.

Nozzle types, positions and spray angles are important factors that will affect the effectiveness of cooling and reagent treatment. Selection of the nozzle type affects the droplet size and the spray pattern. In general, the droplet size needs to fall within a certain optimal range. On the one hand, the size needs to be decreased so as to increase the surface area. On the other hand, the size must not be decreased to the extent where the droplets are light enough to be carried away by the flowing gas. To this end, the reagent is sprayed by the reagent nozzles 171 to form a plurality of droplets with sizes falling with the range from 0.5 mm to 1.5 mm. That is, the preferred droplet size is 1 mm. The cooling nozzles 131 in this embodiment are similarly arranged on a lower annular pipe 503a (see Figure 1) to spray the cooling medium inwardly and downwardly at angles falling within the range from 0° to 40°, with the sprayed cooling medium forming a plurality of droplets with sizes falling with the range from 0.5 mm to 1.5 mm, preferably 1 mm. In an alternative embodiment, some or all of the cooling nozzles 131 may be arranged on a riser portion to spray the cooling medium outwardly and downwardly at angles falling within the range from 0° to 30°.

With the reagent sprayed in such a manner, the second deflector 150 serves to reduce or block the sprayed reagent from mixing and reacting with liquid at the

cooling device 130 to ensure that the wash water is compliant with MARPOL for overboard discharge.

In the present embodiment, the reagent includes Carbamide for reacting with sulphur oxide (SO_x) and nitrogen oxide (NO_x) in the exhaust gas at the lowered temperature (70°C to 100°C) to produce the oxidised byproduct. The produced oxidised byproduct is non-toxic, including such as nitrogen (N₂), carbon dioxide (CO₂), water (H₂O) and ammonium sulphate ((NH₄)₂SO₄), and environmentally friendly and thus, may be discharged to the environment. At the lowered temperature, the cooled exhaust gas reacts with the reagent in an aqueous state. That is to say, the reagent in the aqueous state reacts with the cooled exhaust gas. In contrast, a known SCR technique treats a single pollutant type at a significantly higher temperature, typically exceeding 300°C. Such a high temperature is required for the SCR reagent to decompose and transition into a gaseous state for reaction with the exhaust gas (for example, ammonia).

In the present embodiment, at the lowered temperature, the degree of treatment increases when the reagent pH increases from pH 6.5 to pH 10, and the reagent reacts with the cooled exhaust gas to produce or form a buffer solution of pH 5 to pH 9. The reagent has a concentration not smaller than 40 g/l to achieve an optimal or preferred range of treatment efficiency, as shown in the diagram of Figure 6 (depicting a relationship between concentration, pH and reaction temperature of Carbamide on a scale of NO_x treatment). For optimal absorption, the ratio of NO to NO₂ is preferably equimolar. This means that a

portion of the NO content may be oxidized, through the use of ozone generator or a compressed air system, to form NO₂ in order to achieve a higher efficiency level. Another factor to consider is the residence time of the cooled exhaust gas in the reagent delivery device 170. With or without the grating 160, the time of residence of the cooled gas in the reagent delivery device 170 is preferably between 0.5 seconds to 1.5 seconds. A time of residence shorter than 0.5 seconds may result in an incomplete reaction between the reagent and the pollutants in the cooled exhaust gas. A time of residence longer than 1.5 seconds may also be adopted. After reaction of the cooled exhaust gas with the reagent, the produced oxidised byproduct rises towards the demister 180.

The demister 180 is configured to demist (i.e., to reduce water vapour) the produced oxidised byproduct, with the demisted and oxidised byproduct being subsequently discharged from the treatment chamber 501 via the gas outlet 190 (Step 404). Specifically, the gas outlet 190 is arranged at a top portion of the cylindrical body 500 and fluidly communicates the treatment chamber 501 with an external environment. The demisted and oxidised byproduct has a direction of flow marked in Figure 1 by an up-arrow next to the gas outlet 190.

Figure 7 shows another representation of the apparatus 100 in association with a control and monitoring system 200 (sense-making system) and a water cooling pump 300. The cooling pump 300 is controlled by Variable Frequency Drive (VFD). Water pumped by the water cooling pump 300 may have a temperature ranging from 20° to 30°. In addition to starting up and shutting

down the apparatus 100, the control and monitoring system 200 of this embodiment is configured to handle steady state operations and abnormal conditions of the apparatus 100 with minimal or no human intervention. Some of these automated functions include power saving, thermal shock prevention with
5 respect to the body 500 by the cooling device 130 before the treatment process, optimised injection of the cooling medium based on the engine load, automated soot blowing to prevent nozzle blockage, and storage or discharge of wash water depending on a condition of the wash water. Automated handling of abnormal conditions or situations reduces unnecessary shutdown or outage
10 occurrences, which in turn protects the apparatus 100 and prolongs its lifespan. These capabilities are achieved by taking into consideration various statuses of the apparatus 100 and progressively adjusting relevant parameters for process optimisation. The water cooling pump 300 is controlled by the control and monitoring system 200 to pump the cooling medium to the cooling device 300.
15 The term “wash water” refers to water drained out of the apparatus 100 or specifically from the cylindrical body 500, and may include water used for cooling the exhaust gas.

The control and monitoring system 200 operates according to various
20 parameters, including an engine load, an exhaust gas flow rate, an exhaust gas temperature and levels of emitted NO_x and SO_x.

In this embodiment, cooling and treatment of the exhaust gas are based on a flow rate of the exhaust gas. More specifically, the cooling medium and the

reagent are introduced into the treatment chamber 501 based on the flow rate of the exhaust gas. Figure 8 shows a flowchart 600 of operation of the control and monitoring system 200. Using the flow rate of the exhaust gas, obtained either directly from the engine or measured at the gas inlet 110, the control and monitoring system 200 determines the required flow rates for the cooling medium and the reagent to adjust operations of the respective pumps while constantly measuring the exhaust gas temperature and the treatment quality. If one or more of the parameters fall outside of their respective ranges, the control and monitoring system 200 makes adjustments until the parameters fall within their respective ranges. In such a manner, the overall power consumption can be further reduced and optimised in accordance with an operation status of the vessel.

At Step 601, the control and monitoring system 200 obtains a current reading of flow rate of the exhaust gas, and then proceeds to Step 602. This reading may be obtained from a sensor associated with one of the engine and the gas inlet 110.

At Step 602, the control and monitoring system 200 determines the respective flow rates of the cooling medium and the reagent, and then proceeds to Step 603.

At Step 603, the control and monitoring system 200 sets respective target pump speeds for the pumps of the cooling medium and the reagent, and then proceeds to Step 604.

- 5 At Step 604, the control and monitoring system 200 determines if the current pump speeds meet the respective target pump speeds, proceeds to Step 606 if a result of determination is affirmative, and proceeds to Step 605 for adjusting or controlling operation of the pumps accordingly if otherwise.
- 10 At Step 606, the control and monitoring system 200 determines if the current temperature and the current quality of the exhaust gas are within the respective limits, ends its own operation if a result of determination is affirmative, and proceeds to Step 607 if otherwise.
- 15 At Step 607, the control and monitoring system 200 adjusts (e.g., increases) the pump speeds by, for example, a specific percentage (e.g., 10%), and then proceeds to Step 608.

- At Step 608, the control and monitoring system 200 determines if the pump
- 20 speeds are sufficient for the current temperature and the current quality of the exhaust gas to meet the corresponding limits, proceeds to Step 610 if a result of determination is positive, and proceeds to Step 609 to adjust the pump speed if otherwise.

At step 610, the control and monitoring system 200 waits for a predetermined time (e.g., five seconds) before returning to Step 606.

In this example, a high amount of carbon dioxide results from the combustion process of the engine, and operation of the apparatus 100 adds to the overall power consumption of the vessel. By virtue of the above power saving features of the control and monitoring system 200, the overall power consumption and hence the total carbon dioxide emission can be reduced.

In summary, the apparatus 100 achieves significantly lower volume, weight and power consumption whilst being able to treat a plurality of pollutant types concurrently. Indeed, the apparatus 100 of the described embodiment is able to achieve “simultaneous treatment” of two or more pollutant types such as SO_x and NO_x which may be harmful to the environment. Thus, such pollutant types are removed from the exhaust gas (by reacting with a reagent) prior to discharging the exhaust gas to the environment.

Other alternative arrangements are described below.

In another arrangement, the cooling device 130 may mechanically cool the gas such as by means of a heat exchanger.

A variety of other variations and modifications which do not depart from the scope of the invention will be evident to persons of ordinary skill in the art from

the disclosure herein. The following claims are intended to cover the specific embodiments set forth herein as well as such variations, modifications, and equivalents.

Claims

1. An exhaust gas treatment apparatus, comprising:
 - a treatment chamber;
 - a gas inlet adapted to introduce exhaust gas into the treatment chamber,
 - 5 the introduced exhaust gas having a plurality of pollutant types;
 - a cooling device configured to introduce a cooling medium into the treatment chamber to cool the introduced exhaust gas;
 - a reagent delivery device configured to introduce a reagent into the treatment chamber to react with the plurality of pollutant types of the cooled
 - 10 exhaust gas to produce an oxidised byproduct; and
 - a gas outlet adapted to discharge the oxidised byproduct from the treatment chamber.
2. The apparatus of claim 1, wherein the pollutant types include sulphur oxide
- 15 (SO_x) and nitrogen oxide (NO_x).
3. The apparatus of claim 1 or 2, wherein the reagent includes Carbamide.
4. The apparatus of claim 3, wherein the cooled exhaust gas has a temperature
- 20 falling within the range from 70°C to 100°C.
5. The apparatus of claim 3 or 4, wherein the reagent has a concentration not smaller than 40 g/l.

6. The apparatus of any one of the preceding claims, wherein the reagent delivery device comprises:

a plurality of nozzles configured to spray the reagent at the cooled exhaust gas.

5

7. The apparatus of claim 6, wherein the reagent is sprayed inwardly at an angle ranging from 0° to 40°.

8. The apparatus of claim 6 or 7, wherein the reagent is sprayed outwardly at an
10 angle ranging from 0° to 30°.

9. The apparatus of any one of claims 6 to 8, wherein the reagent is sprayed to form a plurality of droplets with sizes falling within the range from 0.5 mm to 1.5 mm.

15

10. The apparatus of any one of claims 6 to 9, wherein the reagent is sprayed in a full cone spray pattern.

11. The apparatus of any one of the preceding claims, wherein the cooling
20 device comprises:

a plurality of nozzles configured to spray the cooling medium at the introduced exhaust gas.

12. The apparatus of any one of the preceding claims, wherein the cooling medium includes at least one of seawater and freshwater.

13. The apparatus of any one of the preceding claims, wherein the cooling
5 medium is sprayed in a full cone spray pattern.

14. The apparatus of any one of the preceding claims, further comprising at least one of:

a first deflector configured to block entry of liquid from the cooling device
10 into the gas inlet; and

a second deflector configured to block entry of liquid from the reagent delivery device into the cooling device.

15. The apparatus of claim 14, wherein the at least one of the first deflector and
15 the second deflector is cone shaped.

16. The apparatus of claim 14 or 15, wherein the at least one of the first deflector and the second deflector is further configured to reduce a drop in pressure of the exhaust gas across the at least one of the first deflector and the
20 second deflector.

17. The apparatus of any one of claims 14 to 16, wherein the at least one of the first deflector and the second deflector has a serrated edge.

18. The apparatus of any one of the preceding claims, further comprising:
a grating configured to cause the cooled exhaust gas passing through the grating to form a plurality of turbulent vortices.
- 5 19. The apparatus of any one of the preceding claims, further comprising:
a demister configured to demist the oxidised byproduct.
20. The apparatus of any one of the preceding claims, wherein at least one of the cooling medium and the reagent is introduced based on a flow rate of the
10 exhaust gas.
21. An exhaust gas treatment method, comprising:
introducing exhaust gas into a treatment chamber, the introduced exhaust gas having a plurality of pollutant types;
15 introducing a cooling medium into the treatment chamber to cool the introduced exhaust gas;
introducing a reagent into the treatment chamber to react with the plurality of pollutant types of the cooled exhaust gas to produce an oxidised byproduct; and
20 discharging the oxidised byproduct from the treatment chamber.
22. The method of claim 21, wherein the pollutant types include sulphur oxide (SO_x) and nitrogen oxide (NO_x).

23. The method of claim 21 or 22, wherein the reagent includes Carbamide.

24. The method of claim 23, wherein the cooled exhaust gas has a temperature falling within the range from 70°C to 100°C.

5

25. The method of claim 23 or 24, wherein the reagent has a concentration not smaller than 40 g/l.

26. The method of any one of claims 21 to 25, wherein introducing the reagent
10 into the treatment chamber includes spraying the reagent at the cooled exhaust gas.

27. The method of claim 26, wherein the reagent is sprayed inwardly at an angle ranging from 0° to 40°.

15

28. The method of claim 26 or 27, wherein the reagent is sprayed outwardly at an angle ranging from 0° to 30°.

29. The method of any one of claims 26 to 28, wherein the reagent is sprayed to
20 form a plurality of droplets with sizes falling within the range from 0.5 mm to 1.5 mm.

30. The method of any one of claims 26 to 29, wherein the reagent is sprayed in a full cone spray pattern.

31. The method of any one of claims 21 to 30, wherein introducing the cooling medium into the treatment chamber includes spraying the cooling medium at the introduced exhaust gas.

5

32. The method of any one of claims 21 to 31, wherein the cooling medium includes at least one of seawater and freshwater.

33. The method of any one of claims 21 to 32, wherein the cooling medium is
10 sprayed in a full cone spray pattern.

34. The method of any one of claims 21 to 33, wherein the exhaust gas is introduced into the treatment chamber via a gas inlet, the method further comprising:

15 blocking entry of liquid from the treatment chamber into the gas inlet.

35. The method of claim 34, further comprising:

reducing a drop in pressure of the introduced exhaust gas caused by blockage of entry of liquid from the treatment chamber into the gas inlet.

20

36. The method of any one of claims 21 to 35, further comprising:

causing the cooled exhaust gas to form a plurality of turbulent vortices.

37. The method of any one of claims 21 to 36, further comprising:

demisting the oxidised byproduct.

38. The method of any one of claims 21 to 37, wherein at least one of the cooling medium and the reagent is introduced based on a flow rate of the exhaust gas.
- 5